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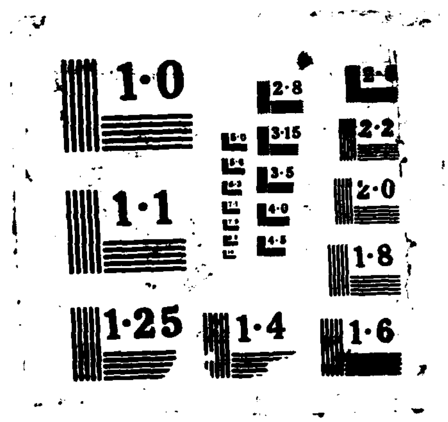
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This investigation was concerned with the experimental and theoretical study of the interaction of a transferred arc plasma jet with a metal block onto which this jet impinges. Problems of this type are of interest in plasma arc remelting processes and also in welding. The study had both experimental and analytical (mathematical) modelling components. The experimental work involved the construction of an apparatus which is essence consisted of a 20 kW plasma jet impinging onto a hemispherical steel block of 200 mm diameter. ~~In~~ the ~~course of the~~ experiment~~, we~~ measured the voltage, the current, the plasma gas flow rate and the evolution of the temperature fields as the metal block was heated up and partially melted.

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19. ABSTRACT (CONTINUED)

The theoretical work had two components.

1. We developed a mathematical representation of the electromagnetic force field, velocity field and temperature field in the plasma jet system, and coupled this to the unsteady state heat transfer in the metal block. Thus, it was possible to obtain a direct comparison between theoretical predictions and experimental measurements. This agreement was good, both regarding the absolute values and the specific trends.

2. The second component of the theoretical work involved the modelling of the heat flow and fluid flow phenomena in typical welding arcs. The reason that this work was undertaken was that experimental data have been reported on such systems by others, regarding both the plasma temperature fields and the plasma-surface heat transfer.

Two major publications resulted from this work:

G. Backer and J. Szekely, "The Interaction of a DC Transferred Arc with a Melting Metal: Experimental Measurements and Mathematical Description," Met. Trans. 18B, 93-104 (1987).

J. McKelliget and J. Szekely, "Heat Transfer and Fluid Flow in the Welding Arc," Met. Trans. 18A, 1139-1148 (1987).

in addition to a M.S. Thesis. Of the personnel involved in the project, Mr. G. Backer is now at the General Motors Technical Center in Warren, Michigan, while Dr. McKelliget is an Assistant Professor at the University of Lowell. Prof. McKelliget is maintaining a research interest in plasma phenomena.

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THE INTERACTION OF A DC PLASMA JET WITH A MELTING METAL: EXPERIMENTAL MEASUREMENTS AND MATHEMATICAL DESCRIPTION

FINAL REPORT

JULIAN SZEKELY

15 MAY 1987

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DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

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TECHNICAL REPORT

INTRODUCTION

The purpose of this investigation was to develop an improved fundamental understanding of how transferred arc plasmas interact with melts of metallurgical interest. The main practical motivation for this work is provided by the fact that plasma arc remelting (PAR) is a potentially attractive technology for secondary processing of superalloys or high-quality steels; however, at present little is known of the actual mechanism of melting upon the interaction between the plasma jet and consumable electrode, or the interaction of the plasma jet and the molten metal pool.

A better understanding of these phenomena could well lead to an improved processing technology.

THE RESEARCH

The work to be described in this report involved both mathematical modelling and experimentation.

Mathematical Modelling

The mathematical modelling work had three main components:

(1) A mathematical model was developed to represent the electromagnetic force field, the velocity field and the temperature field in a typical welding arc, which is one important manifestation of transferred arc systems. This work (described in detail in Appendix 1) was undertaken because measurements do exist concerning these systems; thus there is an immediate basis for the testing of theoretical predictions.

In the statement of the model, allowance was made for the solution of the coupled Maxwell's equations, the Navier-Stokes equations and the differential thermal energy balance equation. The solution required an iterative procedure involving several nesting loops, because of the strong dependence of the electric conductivity of the plasma on the temperature (i.e. the degree of ionization).

As a result of this work, predictions could be made regarding the temperature, velocity and electromagnetic force fields in typical welding arcs, with currents ranging from 100-200 Amperes, and with arc lengths of the order of 10 mm. The theoretical predictions were found to be in good agreement with several independent sets of measurements. More specifically, the predicted temperature profiles agreed well with measurements reported by Pfender, while the predicted current and heat flux distribution on the anode surface agreed well with data reported by Nestor and Eagar. For detailed references, see Appendix 1.

(2) The second component of the mathematical modelling work was to represent the electromagnetic force field, and the plasma velocity and temperature field in a transferred arc plasma produced by a DC plasma torch. While there were some similarities between these two modelling efforts, significant differences included the following:

(i) Both the current and the gas velocities were much higher.

(ii) The gas flow was turbulent.

(iii) The system was confined, so there was recirculating flow.

The theoretical predictions in this case required that the turbulent Navier-Stokes equations be employed.

Here again, predictions were made regarding the electromagnetic force field, the velocity field and the temperature field within the plasma jet.

(3) The third component of the mathematical modelling effort concerned the prediction of the interaction of the plasma jet with an initially solid, hemispherical steel block. Here the approach taken involved postulating a specified, previously calculated heat flux falling on the solid surface

and the associated transient heat conduction and melting. In this analysis allowance was made for convection in the melt pool, by assigning an effective thermal conductivity to the molten phase. The net output of these calculations was a prediction regarding the time-dependent melt solid interface within the steel block, together with associated transient temperature profiles.

Experimental Work

The experimental work involved measuring the temperature profiles into a hemispherical steel block onto the surface of which a plasma jet was made to impinge. These temperature measurements were carried out using thermocouples embedded in the block. In order to carry out these measurements, an apparatus has been constructed, consisting of a transferred arc plasma jet with a nominal power of 30 kW, encased in a reaction chamber which also contained the steel block to be melted. The actual measurements, taken in the course of a given run, included the power input into the plasma (current and voltage), the gas flow rate, the cooling water flow rate and the distance between the plasma jet and the surface of the melting block. These measurements, details of which are presented in Appendix 2, enabled us to test the theoretical predictions. The agreement between measurements and predictions was quite good regarding both the absolute values of the melting rates and the temperature trajectories at various locations within the system, and the effect of process variables, such as the power input and the gas flow rate, on the melting rate.

General Significance of the Project

The significance of the project is that we have been able to develop a quantitative representation as to how a plasma jet would interact with a melting metal block when the system is operated in a transferred arc mode. Theoretical predictions were found to be in excellent agreement with measurements. Thus we have a sound basis for modelling conventional PAR systems, and can have confidence in our ability to describe pool profiles and velocity fields in the molten metal pool, and hence be able to relate the phenomena to the structure of the materials produced.

Perhaps a greater potential significance of the work is that the fundamental understanding thus produced may be used to develop novel plasma remelting operations such that the pool size may be carefully controlled. Segregation may thus be minimized.

PERSONNEL

Mr. G. Backer, whose M.S. thesis work was supported by this investigation, is now working at the General Motors Technical Center in Dearborn, Michigan.

Dr. J. McKelliget, who received partial support as a post-doctoral associate while working on this project, is now an Assistant Professor of Mechanical Engineering at the University of Lowell.

It follows that in addition to generating useful, well-documented technical information, this project has also contributed to the training of technical personnel who are now in their turn contributing to the U.S. economy and education.

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1. J. McKelliget and J. Szekely, "Heat Transfer and Fluid Flow in the Welding Arc," Met. Trans. 17A, 1139-1148 (1986).
2. G. Backer and J. Szekely, "Interaction of a DC Transferred Arc with a Melting Metal: Experimental Measurements and Mathematical Description," Met. Trans. 17B, 95-104 (1987).
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